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Design and Evaluation of an Affordable Drip Irrigation System for Backyard Garden in the Forest-Savannah Transition Zone of Ghana

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Abstract

The paper sought to design and evaluate a simple and affordable drip irrigation system for improving yield in backyard maize in Ghana. The design consisted of locally made system using easily available materials. The system was calibrated to obtain uniform flow. Hydraulic performance of the system was determined. A Randomize Complete Block Design with three depth treatments (T1=0cm, T2= 20cm and T3 = 40cm) and four replications was used. Plant parameters such as height, leaf length, leaf diameter and stem girth were measured weekly. The uniformity coefficient (UC) ranged from 98 to 99.8% signifying excellent water uniformity application. However, Flow and Coefficient of Variation (CV) values were below standard (ranged between 57.62 % to 60.60 % and 19.8 % to 23 % respectively) due to variation in pressure head. Maize growth under the developed drip lines gave good results in all the growth parameters and yield except the T3 but were statistically similar in all the treatments.

Keywords: Drip irrigation; uniformity coefficient; flow variation; Coefficient of variation.

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1. Introduction

Maize is the third most important cereal crop after wheat and rice and is recognized as a preferred staple food for over 1.2 billion people living in developing countries across the globe [1]. In Ghana, it is the number one crop, in terms of production and consumption, and accounts for 50-60% of total cereal production [2, 3]. Despite the importance of maize in mitigating the present food insecurity in Ghana, productivity is mainly under rain-fed conditions with uneven distribution and prolong and intermittent drought [4, 5]. Studies show that, due to the unpredictable nature of rainfall in the country, maize production is prone to drought stress and has resulted in significant yield loss [6, 7]. As its brief life cycle takes place in a critical time period for the availability of water, irrigation plays a determining role in maize production.

Until the beginning of this millennium, maize had always been irrigated with highly inefficient methods. Still today, in many parts of the world, including Ghana, maize is watered by flooding or lateral infiltration of the furrows. The most commonly used method is sprinkling by self-propelled machines which need high flow rates and energy, working at pressures in the order of 10-12 bar, giving water use efficiency levels about 60% [8].

In an attempt to increase maize yield and water use efficiency whilst reducing energy cost, drip irrigation has recently been developed for the crop. The method offers an excellent alternative to sprinkler irrigation, and has several advantages including more efficient use of water, less labour cost, less usage of fertilizer, less energy requirement, reduced salinity risk, reduced soil erosion, equitable water distribution and higher crop production [9, 10, 11]. Recent studies show that drip irrigation can increase maize yield by 40% providing high quality grains as a result of fewer periods of water and nutrient stress [8].

This work has been done by [12] as a supplementary irrigation in a more humid environment and on a sandy-clay soil. The objective of the study was to find out how the design, , a simple polyvinyl chloride (PVC) pipe drip system with drip lines placed at different depths below the surface, will perform under 100 % irrigation (dry season), in a forest-savannah transition zone of Ghana with *Akposoe* maize variety as a test crop.

2. Materials and Methods

2.1 Description of the study site

The study was carried out at the College of Agriculture Education (CAGRIC), University of Education, Winneba, Multi-purpose Nursery. CAGRIC is located in the Ashanti Region at 57 km North of Kumasi on the Kumasi-Ejura trunk road. Geographically, it lies within longitudes 0.05^o and 1.30^o West and latitudes 6.55^o and 7.30^o North. The annual rainfall ranges between 1270 mm and 1524 mm with the mean monthly being 91.2 mm. The rainfall pattern in the area is bimodal (with two peaks). The mean monthly temperature is between 25 ^{o}C and 32 ^{o}C [13].

2.2 Design of the system and calibration of flow

The drip irrigation system was designed using locally made and easily available materials such as : ½ inch Poly

Vinyl Chloride (PVC) pipes, ½ inch end cup, ½ inch elbow, ½ inch plastic control taps, funnel, graduated cups and 50 m long water hose. The system was designed using the following information as the basic guideline:

- Time of irrigation = 30 minutes
- Area to be irrigated = 240 m^2 (4 plots of 10 m x 6 m)
- Crop (Maize) spacing= 0.75 m x 0.35 m
- Minimum Pressure head = 0.85 m
- Maximum pressure head = 1.15 m

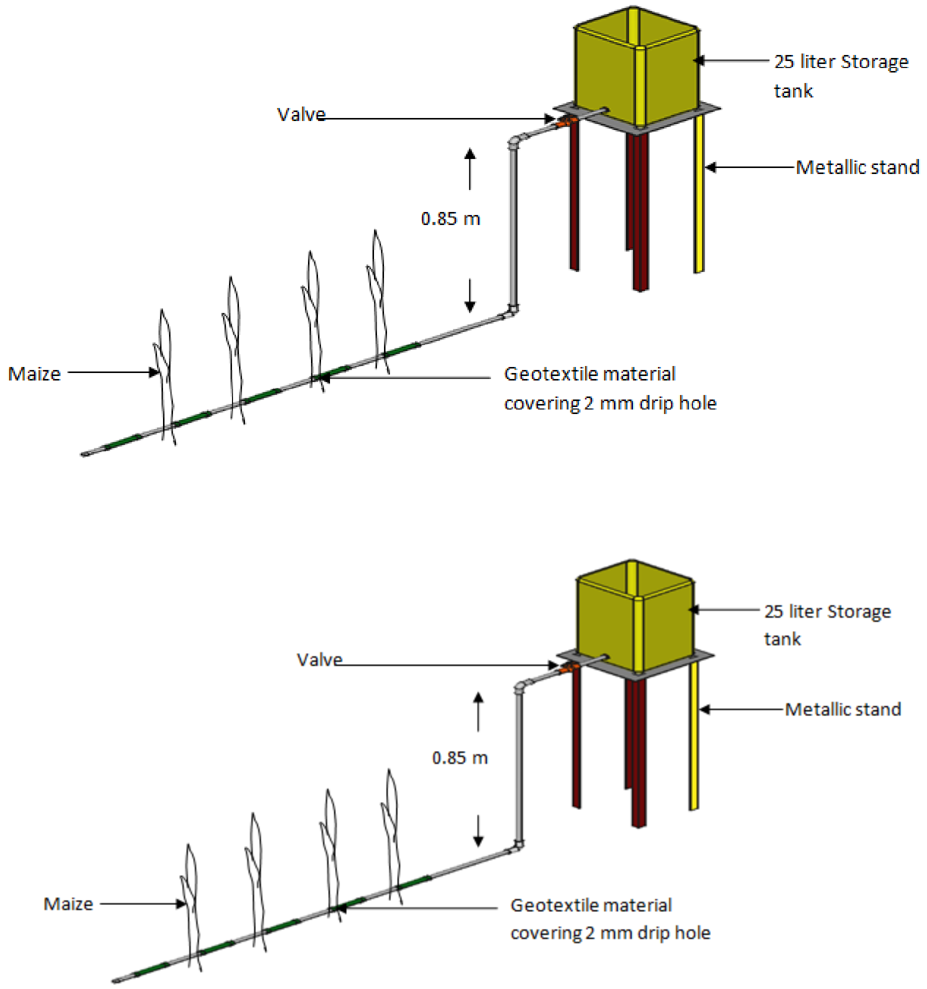

Figure 1: Drip system design with crop (maize)

In order to obtain a uniform flow of water from the laterals for all the laid pipes, they were laid horizontally using the spirit level. 16 drip holes of 2 mm diameter each per lateral of 6 m with an end cup fixed at the other and joined to a pipe of 0.85 m height was set up and calibrated for uniformity of flow. The set up was connected to the main pipe through the elbows joint to supply water from the storage tank to the main laterals through the drip holes. Catch (collector) cans were placed on a leveled surface to make sure that there was even distribution of water in the drip holes. A storage tank of 25litre capacity was used and placed at a height of 0.85m to serve as the flow head (Figure 1).

2.3 Field Procedure

Forty-three (43) PVC pipes of length 22.5 m each with end cups at the other ends were used. Drip holes of 2 mm diameter were made at a spacing of 0.35m on each pipe to correspond to the intra-row planting distance of maize. Elbows were used to connect the extension pipes to the main lateral. A 0.06 m × 0.39 m geotextile material and a flexible copper wire of 0.25 length were tightly fixed on the drip holes to ensure water flow out in drips, which served to soak the medium and also to control drip flow tightly (See Figure 2). The P.V.C pipes were laid at different depths of 0 cm, 20 cm and 40 cm.

Figure 2: Field layout

The experimental design consisted of a randomized arrangement of three water application depths. The layout consisted of four blocks design (RCBD). The treatments were water application depth at 0 cm (T1), 20 cm (T2) and 40 cm (T3). Each plot measured 6 m × 10 m. The field layout and blocking is shown in Figure 2. The time ranges of individual growth as observed and adopted for the experiment based on the variety grown for the experiment are shown in Table 1.

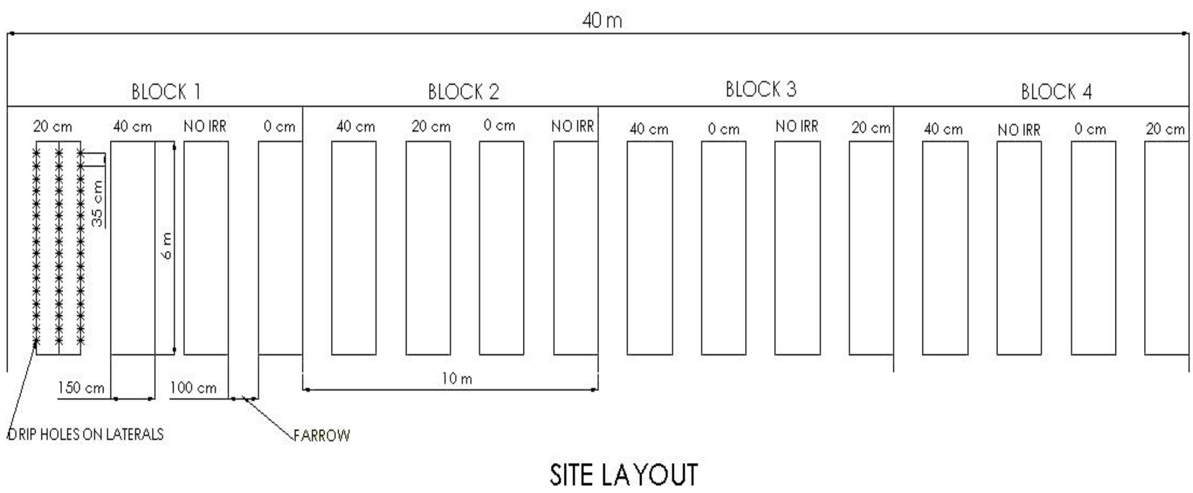

Figure 3: Lateral layout of the experimental field

Table 1: Duration and period within the various growth stages

Growth stages	Duration (days)	Day after planting (days)	Period
Initial stage	14	14	January 8th to January 21th
Crop development stage	24	38	January 22th to February 14th
Mid stage	27	65	February 15 th to March 12th
Late stage	20	85	March 13th to April 1st

The *Akposoi* maize variety was planted at a spacing of 0.75 m x 0.35 m after the soil has been irrigated to 50% field capacity. An inorganic fertilizer (NPK-15:15:15) was applied as recommended by Soil Research Institute of the [14] CRI of CSIR (2011). Irrigation was scheduled for every three days. Five plants from each replicate were randomly selected and tagged for measurements. Plant growth parameters such as plant height, leaf length, leaf diameter, and stem girth were collected every week.. The results for all the treatments were statistically analyzed using analysis of variance (ANOVA). A 5 % level of significance was used for all the analysis. In order to evaluate the performance of the drip irrigation system, three widely-used parameters for measuring emitter discharge uniformity (Flow variation, (Q_{var}), Uniformity coefficient (*UC)* and *Coefficient of Variation (CV)*) were used and defined as follows:

$$Q_{var} = \frac{100\times(Q_{max}-Q_{min})}{Q_{max}} \quad \text{……(1)}$$

$$UC = 100 \times \left[1 - \left(\frac{\frac{1}{n}\sum_{i=1}^{n}|q_i-\bar{q}|}{\bar{q}}\right)\right] \quad \text{……(2)}$$

$$CV = \frac{s}{\bar{q}} \quad \text{……(3)}$$

Where Q_{max} = maximum emitter (drip hole) flow rate, Q_{min} = minimum emitter (drip hole) flow rate, q = discharge, $\bar{q}$ = Mean discharge, n = number of (drip holes) emitters evaluated,

s = standard deviation of (drip flow) emitter flow rate,

3. Results and Discussions

3.1 Hydraulic Performance of the drip irrigation system

The hydraulic performance of the system is presented in Table 2. The calculated UC for the three levels of water application ranged from 98% to 99.8%. According [15,16] classification, the water distribution of the system is excellent. However, the calculated CV and Qvar ranged from 19.8% to 23% and 57.56% to 60.60% respectively. This, according to [17] classification, is below standard and does not agree with [18]. According to [19], two effective factors on variation of the water pressure in trickle irrigation system are the pressure head loss and the field topography. The pressure head was exposed to the atmosphere and the tap was turned off whenever the laterals became full and this could affect the flow.

Table 2: Performance criteria for evaluating the drip irrigation system

Quantity of Water applied (L)	Total time of Flow (Sec)	Flow Variation (Qvar) %	Uniformity Coefficient (UC) %	Coefficient of Variation (CV)%
33	1923	57.62	99.8	19.9
75	4371	57.56	98.0	19.8
125	7285	60.60	98.0	23.0

3.2 Effect of water application on plant growth parameters

The variation of different depth of water application on maize growth parameters is presented from Figure 4 to Figure 7. The soil was watered to field capacity by the designed irrigation system before sowing. From germination to the end of week two (2), all three treatments had the same growth because they depended on the food stored in the endosperm until the nodal root system developed later [20]. From week two (2) to three (3) there was a drop in growth by all treatments because the starchy endosperm's nourishment had been used up and the seminal root system were elongating downward into the soil but not long enough for plants to absorb sufficient water from the placement depth. From week three (3) to four (4), the seedlings were at six leaf stage on the average and the nodal roots at this stage had elongated to assess enough water from the delivery points, for maximum photosynthesis, hence the increased growth by all treatments.

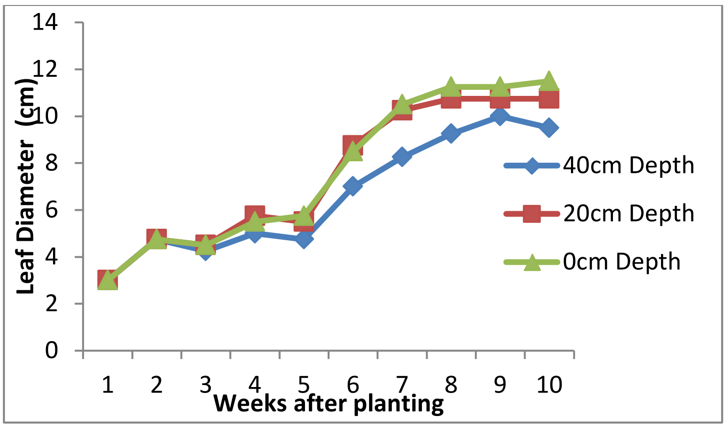

Figure 4: Effect of depth of water application on maize leaf diameter

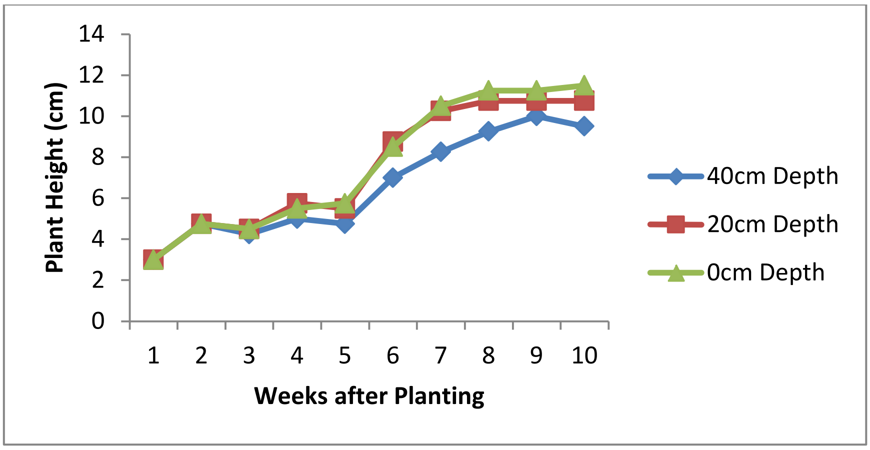

Figure 5: Effect of depth of water application on maize plant height

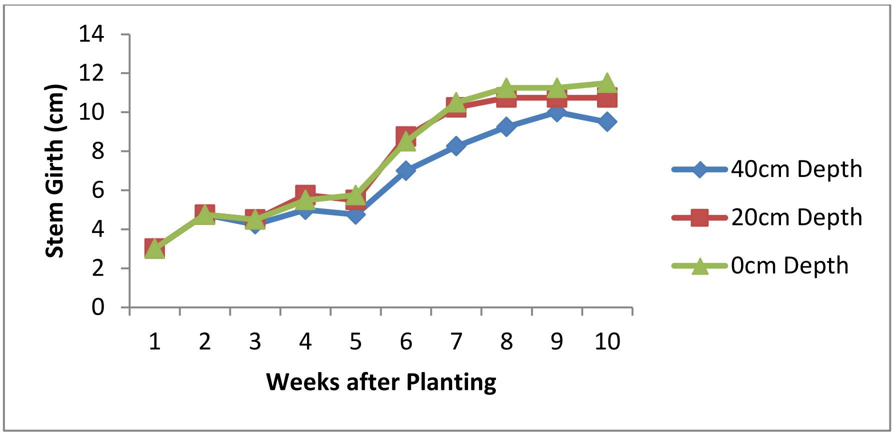

Figure 6: Effect of depth of water application on maize stem girth

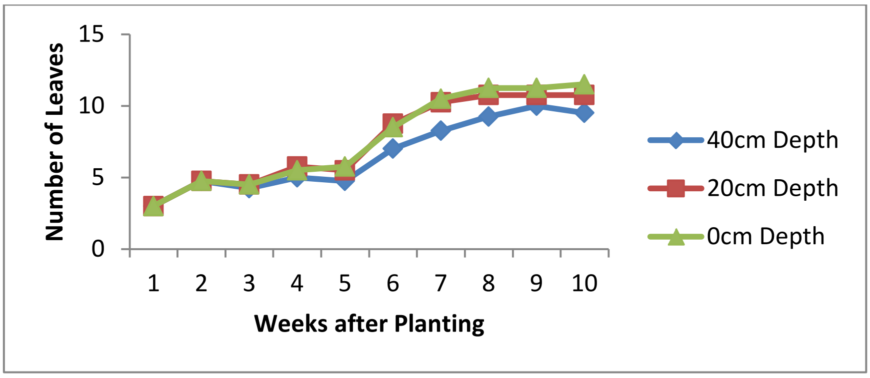

Figure 7: Effect of depth of water application on number of leaves of maize

From week four (4) to five (5) there was a decrease in seedling growth which could be attributed to the fact that there was a wider leaf diameter, more leaves and increase in nodal roots development which called for high uptake of water and nutrients. Also, because irrigation was scheduled at three (3) days interval the high evapotranspiration rate during the period made the top layer of the soil (0-15cm) dry up by the end of second day. From week five (5) to seven (7) there was a sharp increase in growth in all treatments, because the seminal roots as well as the nodal root had developed enough to assess water and nutrients at the various placement depths.

Even though there was an increase in growth in all the treatments from week five (5) to ten (10), there were variations in the growth rates. For T1 the nodal roots assessed water at both the surface and below surface and when there was water loss at the surface it was able to absorb water at the 20cm depth placement. Since the nodal roots of T3 could not assess sufficient water and nutrients and had to rely on capillary action which is slow, it was under stress which affected its photosynthetic processes leading to its least performance. From week seven (7), the seedlings had tasseled and ear formation started. T1 performed better, in terms of growth parameters of maize, than T2 and T3 because it was able to assess water at the surface as well as the zone of T2. T3 performed the least because the length of nodal roots had not reached the water placement point and therefore depended on capillary water. In general maize growth under the developed drip lines gave good result in all the growth parameters. Plant height, stem girth, leaf diameter and number of leaves under designed drip lines were statistically similar in all the treatment except the T3 depth.

3.3 Yield

The yield of dry grain at 13.5% moisture content was highest (5, 945 kg h^{-1}) from pipe placed at 20 cm depth (T2) (Figure 7), agreeing with [12] even though he carried his research in a more humid zone with lower evapotranspiration but similar soil conditions. The ANOVA showed no significant ($P < 0.05$) difference in yield of dry grain between the depth of pipe placement of 40 cm, 20 cm and 0 cm. Water from the 20 cm depth pipes were sustained by natural mulching by the top soil from the harsh weather conditions as reported by [21] who indicated higher water use efficiency and yield in subsurface drip irrigation compared to surface.

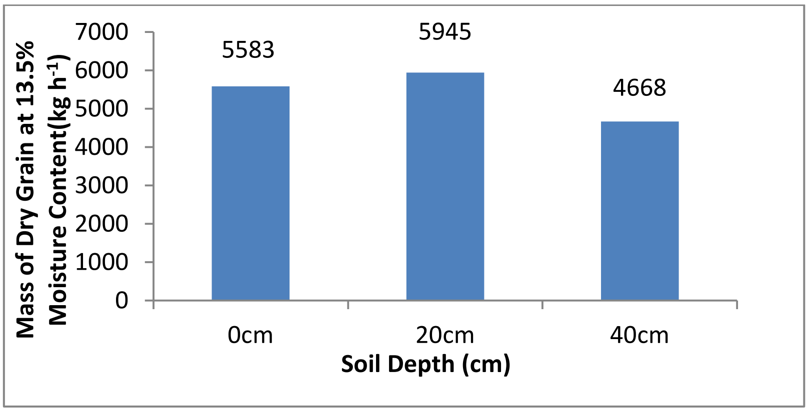

Figure 8: Mass of dry grain at 13.5% moisture content (kg ha^{-1}) of the various treatments

4. Conclusion

The study has shown that the drip irrigation system designed using PVC pipes in [12] can apply irrigation water efficiently under sandy loam and forest savanna transition conditions for proper growth and yield of maze under 100 % irrigation condition in the Forest-Savannah transitional zone of Ghana if only they are well designed and maintained properly. However, the 20 cm subsurface placement had highest effects on the Akposoe maize in both growth parameters and yield, a confirmation of [12] publication. The water application uniformity was found to be above 90%, which describes that the drip irrigation was designed on the basis of proper scaling and dimensions. However the system may be improved by taking steps to reduce pressure head loss. It is only applicable in the backyard garden.

5. Recommendations

1. A bigger central polytank may be used to supply water to minimize the flow variation and to determine how much time could be saved from water application since filling individual tanks is time consuming.
2. The system should be tried under fertigation and its long term effects on the soil and the geotextile material at the various depths of placement of the pipes.
3. The design could be tested on vegetables.

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